

ASTRONOMY 9: HISTORY OF COSMOLOGY

Handout #16

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The Netownian Synthesis

I. Rene Descartes (1596–1650, France)

- “I think therefore I am.” Mind/matter, existence of God and the soul
- Application of algebra to geometry \Rightarrow Cartesian geometry
- Realizes circular motion is “unnatural” (forced)
- Denied possibility of Void
- Matter infinitely divisible, filling all space
- Denied that action could operate at a distance (gravity)
- Forces must operate through direct physical contact
- “Vortices” carry planets around the Sun
- Theory influential in France even 100 yrs after Newton!
- Seeds of the “mechanical universe”, man as “master” of nature
- Remote God sets machine in motion but need not intervene

II. Sir Isaac Newton (1642–1727, England)

- Culmination of scientific revolution; laid foundations of rational scientific world-view until 20th century!
- 1642: Born Christmas day, father died earlier
- 1646: Mother departs and leaves Isaac with grandmother
- 1665: Cambridge graduation
- 1665–1667: Home due to plague: invents calculus (also Leibniz), seminal work on mechanics, theory of color, extension of gravity to planets!
- 1669: Lucasian professorship at Cambridge
- 1671: Invents reflecting telescope
- 1687: Publishes masterful *Principia (Mathematical Principles of Natural Philosophy)* in Latin
- 1693: Temporary insanity
- 1704: Publishes *Opticks*
- Fragmentary state of physical knowledge before Newton
 - Kepler’s 3 laws of planetary motion
 - Galileo’s ideas of inertial motion and free fall on Earth
 - Two different physics: terrestrial and celestial
- Background definitions for Newton’s Laws of motion
 - **Acceleration:** change in velocity (speed *or* direction) [m/s²]
 - **Force:** push/pull, strength of the agent of change in motion [Newtons (metric), pounds (imperial)]
 - **Mass:** measure of inertia, resistance to change in motion [kg]
 - **Absolute space and time:** static background arena, completely independent of observers
- Three **laws of motion**
 1. Objects continue in state of rest or uniform straight-line motion unless acted on by a force
 2. $F = ma$: change in motion is proportional to the force (and in the same direction)
 3. To every action there is an equal and opposite reaction
- Story of the apple: the Moon is falling! Example of firing projectile from a high mountain
- Celestial physics the *same* as terrestrial!
- Universal **law of gravitation**
 - Force points towards centers (of mass)
 - Distance to Moon is $60\times$ radius of Earth
 - Distance “fallen” by Moon in 1 sec is $1/3600$ th of distance fallen by object at Earth’s surface

- $F \propto 1/r^2$, $F \propto M_1 M_2 \Rightarrow F_{\text{grav}} = GM_1 M_2 / r^2$
- $G \approx 6.7 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$ (measured at Cavendish, 1798)
- Spherical masses can be treated as if all mass is in a point at the center!
- Note: **weight** is not the same as mass!
 - * Weight is the *force* of gravity on an object: $F = mg$
 - * g is the gravitational acceleration: $g = GM/r^2$
 - * At Earth's surface, $g \approx 10 \text{ m/s}^2$
 - * So weight depends on where you are, mass doesn't!
- Problem of action at a distance
 - * What is gravitation?
 - * Newton: "I feign no hypotheses..."
- With these laws, Newton can *derive* Kepler's 3 laws: cosmology understood from simple physical principles!
 - Kepler 1: Newton gave geometrical proof that under central inverse-square force, orbital path is elliptical
 - Kepler 2: Geometrical proof for *any* central force
 - Kepler 3: Follows from $F = ma$ and $F = GMm/r^2$:
 - * Take special case of circular orbit (Newton did ellipses too!) with $M \gg m$
 - * For uniform circular motion, $a = v^2/r$
 - * $GMm/r^2 = mv^2/r \Rightarrow v^2 = GM/r$
 - * $v = 2\pi r/P \Rightarrow 4\pi^2 r^2/P^2 = GM/r$
 - * $P^2 = 4\pi^2 r^3/GM \Rightarrow P^2 \propto r^3$
- Comets: also moving in elliptical orbits determined by Newton's laws
 - Halley: guessed comet of 1682 same as 1531, 1607
 - Newton computed orbit, correctly predicted return in 12/1758
 - Spectacular confirmation of Newton's ideas
- Correct, quantitative explanation for tides
 - Gravitational attraction of Moon greater on side of Earth closest to Moon, smaller on side farther away
 - Water pulled by difference in these forces relative to force on the whole Earth
- Earth is oblate (bulges at equator) due to rotation
- Computes 26,000-year precession of equinoxes
 - Moon's gravitational force on oblate Earth tries to tip Earth's axis
 - Earth's axis turns like that of a spinning top
- Arguments with Hooke over nature of light: "standing on the shoulders of giants" (Hooke was very short)
- Strong interest in alchemy, theology, and magic
- Viewed Universe as manifestation of God's power
 - Noted planets *perturb* each others orbits
 - Thought perturbations add up, solar system unstable
 - * Note: Paths of two bodies interacting can be solved exactly, three or more cannot
 - * Stability of the solar system over billions of years is a hard problem even today!
 - * Chaos: positions after long time are *extremely* sensitive to starting conditions
 - God required to constantly intervene to keep things in order
 - Also necessary to explain gravity: magical action at a distance
- Newton's cosmology
 - A finite Newtonian universe would collapse!
 - So Universe must be infinite, homogeneous
 - God's hand again required for stability
 - Implication of Newtonian physics: Mechanistic, deterministic cosmos: if all forces, positions and velocities are known, the future (and past) can be determined exactly (in principle)—room for free will?